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# Performance Analysis of Rooftop PV Systems in Abu Dhabi

Mona Al Ali, Mahieddine Emziane*

*Solar Energy Materials and Devices Laboratory*
*Masdar Institute of Science and Technology*
*P.O Box 54224 Abu Dhabi, UAE*

**Abstract**

This study presents the results obtained from simulated performance monitoring of seven different roof mounted PV systems in Abu Dhabi, the largest of UAE's emirate. Data were analyzed to evaluate the suitability of PV systems for installations in different types of buildings in the UAE. The PV systems consisted of amorphous silicon (a-Si) and polycrystalline silicon (p-Si) PV technologies. Different performance evaluation parameters are presented. The results give an indication of the system performance and provide a basis for economic and environmental assessment of the PV generated electricity.


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*Keywords:*Photovoltaics; Energy yield; Performance ratio; Efficiency; Capacity factor

## 1. Introduction

The electricity consumption in the United Arab Emirates (UAE) has increased by 12% per annum from about 60,000 GWh in 2006 to 85,000 GWh in 2010 [1]. Looking forward, the electricity peak demand in Abu Dhabi (the capital of the UAE) is expected to increase more than four-fold in just two decades, from 5,616 MW in 2008 to 25,530 MW in 2028 [2]. To meet this increasing energy demand, the UAE relies heavily on gas and oil. As a matter of fact, 78-82% of the country generation capacity is based on gas turbine generators, and 17-22% is based on steam turbine generators. As a result, the UAE has a high ecological footprint per capita, and it actually had the world's highest in 2010 [3]. The government of Abu Dhabi has recently committed to have 7% of its generation capacity from renewable resources and mainly from solar energy by the year 2020 [4]. This commitment to changing the energy mix to a more sustainable one has been demonstrated by launching the Masdar Initiative and other renewable energy

* Corresponding author. Tel.: +971.28109140; fax: +971 2 6899121.
*E-mail address:* memziane@masdar.ac.ae.


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programs. Electricity generation using photovoltaic (PV) systems is important, reliable and has the potential to play a significant role in $CO_2$ emissions mitigation by becoming one of the major future sources of electricity generation. In 2009, the Abu Dhabi government announced a new financial incentive program for small scale electricity generation for Abu Dhabi. So far, eleven rooftop pilot PV systems were installed with a cumulative capacity of 2.3 MW that is expected to generate 4.025 GWh/year of electricity and save about 3,220 tons of $CO_2$ per year.

The aim of this study is to present the results obtained from simulated performance monitoring of seven different roof mounted PV systems in Abu Dhabi. Data were analyzed to evaluate the suitability of these PV systems for installations in different type of buildings in the UAE. The PV systems are described and different performance evaluation parameters are presented. The performance parameters calculated include: annual energy generated, final yield ($Y_F$), PV module efficiency, system efficiency, inverter efficiency, performance ratio (PR), capacity factor (CF), energy payback time (EPBT), and $CO_2$ emission reductions.

## 2. Description of the PV Systems and Methodology

The seven PV systems were installed on the roof top of different buildings in Abu Dhabi. They consist of amorphous silicon (a-Si) and polycrystalline silicon (p-Si) PV technologies, rated power, and sizes. The PV module specifications of the seven PV systems are shown in Tables 1.

This section analyzes the results obtained from PVsysts Project Design. PVsyst V5.0 [5] is a software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transport) PV systems. It includes extensive meteo and PV systems components databases, as well as general solar energy tools. PVsyst V5.0 offers three different levels of PV system study, corresponding roughly to the different stages in the development of real projects.

In this research, PVsyst was used to perform a detailed analysis of the seven different PV systems. The first step is to define the PV system type, grid connected project in Abu Dhabi in this case. The plane orientation, fixed tilt plane in this study, was then defined by choosing the tilt angle. After that, the system properties like the system size, the PV modules and the inverter types were defined. After identifying all the input data, the next step is running the simulations. The simulation process involves several variables which are available as monthly tables and graphs in the result file.

The seven different installed grid connected PV systems in Abu Dhabi, were investigated to analyze their technical performance, total energy generated, final yield, performance ratio, capacity factor. Other important parameters such as EPBT and $CO_2$ emission reduction were also evaluated.

Table 1. PV system specification of the seven projects

| PV system | Type | Power module ($W_p$) | System size ($kW_p$) | Module efficiency (%) | Inclination (°) | Area ($m^2$) |
|---|---|---|---|---|---|---|
| System1 | a-Si | 95 | 296.4 | 6.7 | 3 | 4,484 |
| System2 | p-Si | 280 | 129.4 | 14.4 | 22 | 873 |
| System3 | p-Si | 220 | 105.6 | 13.4 | 20 | 788 |
| System4 | p-Si | 280 | 305.76 | 14.4 | 10 | 1,983 |
| System5 | p-Si | 280 | 116.48 | 14.4 | 25 | 807 |
| System6 | p-Si | 280 | 14.56 | 14.4 | 25 | 87 |
| System7 | p-Si | 280 | 54.88 | 14.4 | 15 | 384 |

## 3. Results and Discussion

### *3.1. Energy output*

Fig. 1 shows the monthly total energy generated by these seven PV systems. The energy generated by System1, a-Si, varied between 28,150 kWh in January and 50,170 kWh in May where it has the best output when compared with the other simulated p-Si PV systems. However, the energy output of System4 p-Si was better than System1 in winter and spring seasons.

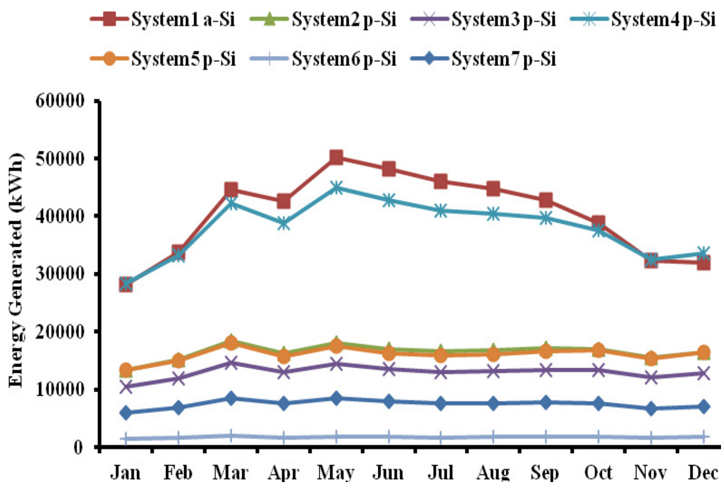


Fig. 1. Monthly total energy generated from the seven simulated PV systems

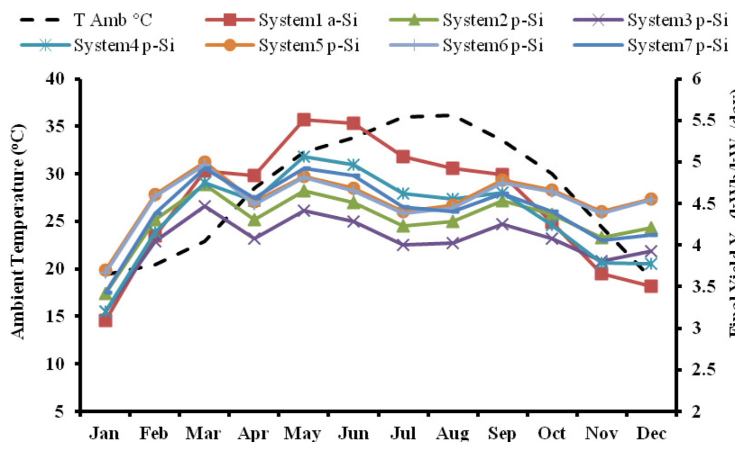


Fig. 2. Monthly average final yield for the seven simulated PV systems against the ambient temperature

### 3.2. Final yield ($Y_F$)

Fig. 2 shows the variation of the monthly average $Y_F$ for the seven PV systems against the ambient temperature. $Y_F$ for System1 (a-Si) seems to generally increase as the ambient temperature increases during the summer and then starts to decrease until it reaches its minimum yield in January. However, $Y_F$ for the other p-Si PV systems performs better in winter when the temperature is lower compared to a-Si of System1. The reason for this is attributed to the lower temperature coefficient of a-Si PV modules as compared to p-Si.

### 3.3. Performance ratio (PR)

Fig. 3 shows the performance ratio of the seven PV systems plotted against the ambient temperature. From this figure, it can be seen that the PR generally decreases when the temperature increases and vice versa, for all the seven PV systems. Although System1 with a-Si thin film has lower PV module, system and inverter efficiencies, it has a better PR (82% in January and 76% in August) compared to the other p-Si PV systems.

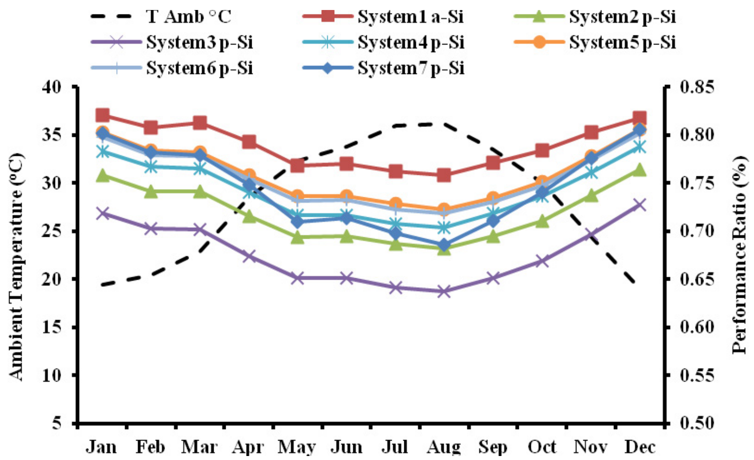


Fig. 3. Monthly performance ratio for the seven simulated PV systems

### 3.4. PV system and inverter efficiencies

Fig. 4 shows the monthly average PV system efficiency and inverter efficiency for System1 which consists of a-Si thin film PV modules and System5 which consists of p-Si PV modules. The graph shows that the PV system efficiencies for System1 varied between 5.3% in January and 4.9% in August. Those values are lower than the values obtained for System5 which has a system efficiency that varies between 11.5% in January and 10.4% in August. The monthly average inverter efficiency for System1 varied between 95.5% in January and 95.7% in June, which is lower than the inverter efficiency of System5 that varied between 97.8% in January and 97.8% in June.

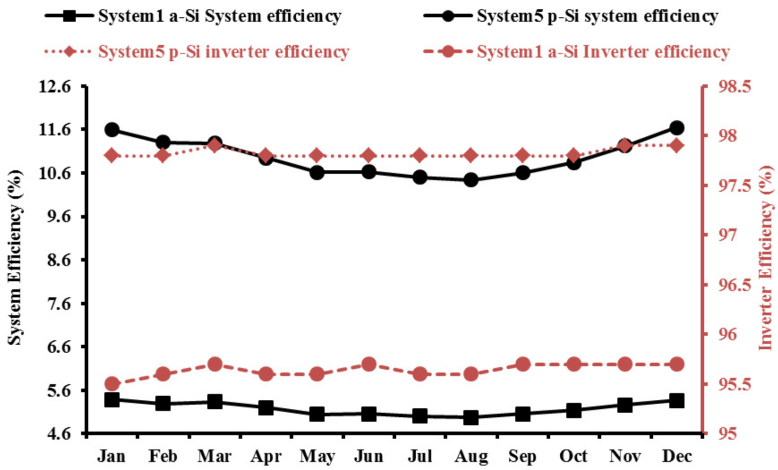


Fig. 4. Monthly average PV system and inverter efficiencies of a-Si and p-Si PV systems

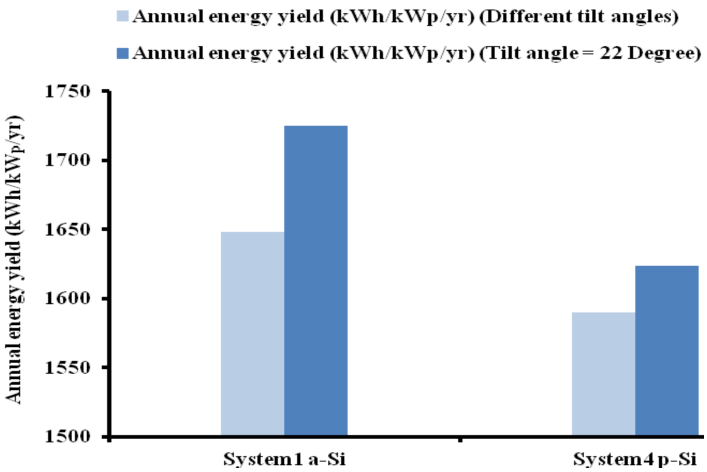


Fig. 5. Annual energy yield comparison of a-Si and p-Si PV systems at two different tilt angles

### 3.5. Tilt angle effect

In dusty and humid climates like the UAE, the solar irradiance is often of a diffuse nature to a large extent due to the scattering of sunlight. In a climate with more direct solar irradiance, it is important that the PV module faces the sun to maximize the energy yield resulting in a tilt angle optimized for the location ($22^{o}$ for our case). Two different PV systems (System1 and 4) with different PV technologies have been selected among all the PV systems analyzed in this study to evaluate and compare their total annual energy yield with different tilt angles. There is no information regarding the reason why System 1 and 4 have been installed with tilt angles of $3^{o}$ and $10^{o}$, respectively. This analysis has been done to prove whether the tilt angle has a direct impact on the energy yield of the PV systems. Table 2 shows a comparison of the annual energy yield of the two different PV systems at two different tilt angles. Fig. 5

shows that the total annual energy yield for the PV systems with a tilt angle of 22$^{o}$ is greater than the total annual energy yield under their real installation angles. Changing the tilt angle for System1 and 4 resulted in 5% and 2% increase in the total annual yield, respectively, which shows that the tilt angle has a significant impact on the energy yield.

Table 2. Comparison of annual energy yield of two different PV systems at two different tilt angles

| PV system | Type | Annual energy yield at different tilt angle (kWh/kW$_p$/yr ) | Annual energy yield at an optimal tilt angle=22$^o$ (kWh/kW$_p$/yr ) | Percentage increase (%) |
|---|---|---|---|---|
| System1 | a-Si | 1,648 at 3$^o$ | 1,725 | 5 |
| System4 | p-Si | 1,590 at 10$^o$ | 1,624 | 2 |

### *3.6. Capacity factor (CF)*

Having the annual energy output of the PV systems, CF can be calculated. CF represents the ratio of the energy produced by the PV systems over a year to its rated power. The annual energy production and CF of the seven PV systems are presented in Fig. 6. The higher the capacity factor, the better the PV system. The results show that the CF for the PV systems was in the range of 16-19 %. PV system1 with a-Si have higher CF than some Systems with p-Si.

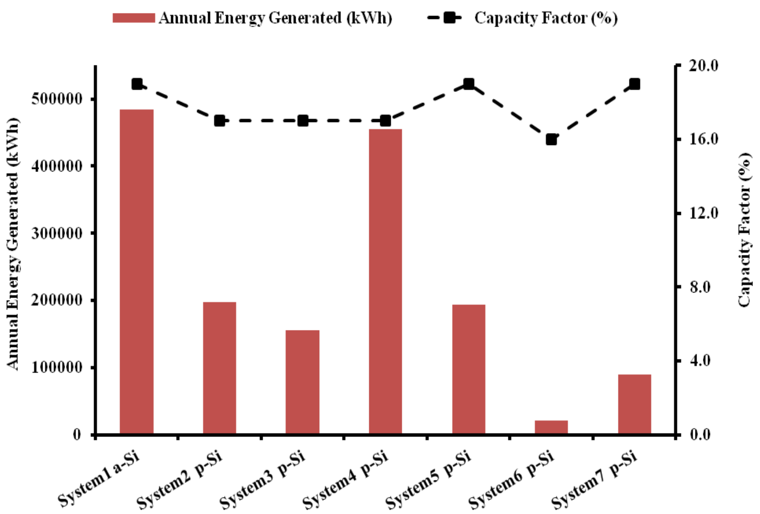


Fig. 6. Annual energy production and CF for the seven PV systems

### *3.7. Energy payback time (EPBT)*

EPBT is the number of years required to get back the energy used to manufacture a PV system and dispose of it at the end of its lifespan [6]. EPBT can be calculated by dividing the total embodied energy over the amount of energy generated by the PV system per year. For the embodied energy of our PV systems we referred to other studies and consider the similarity while using the energy output of the PV systems from this study. The total embodied energy required for the fabrication of the PV modules and balance of system (BOS) are assumed to be 1,018 kWh for p-Si, and 871 kWh for a-Si [7]. Table 3 shows the EPBT of the seven PV systems, and the results indicate that the EPBT is in the range of 8-4 years for our different PV systems. The difference in EPBT was mainly caused by different factors such as the installation size, location and conditions, and the PV module technology used.

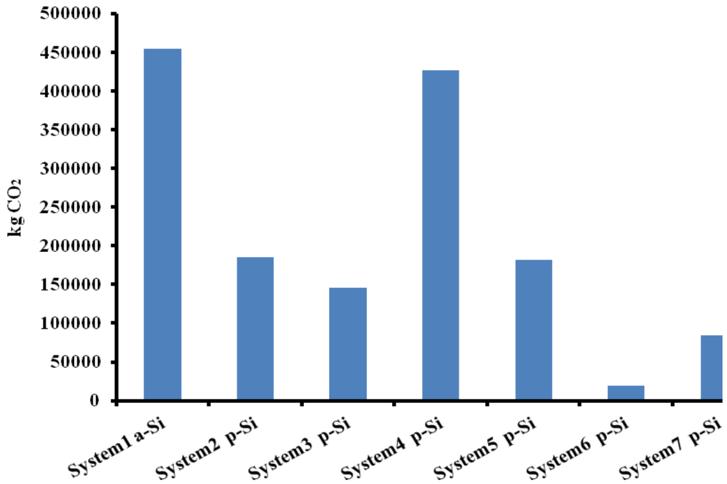


Fig. 7. The equivalent saved $CO_2$ emissions from the seven simulated PV systems

Table 3. EPBT of the seven PV systems

| PV system | Annual energy generated (kWh) | PV module area ($m^2$) | Energy generated per Area (kWh/$m^2$) | EPBT (years) |
|---|---|---|---|---|
| System1 a-Si | 484,340 | 4,484 | 108 | 8.1 |
| System2 p-Si | 197,890 | 873 | 227 | 4.4 |
| System3 p-Si | 156,040 | 788 | 198 | 5.1 |
| System4 p-Si | 455,120 | 1,983 | 230 | 4.4 |
| System5 p-Si | 193,480 | 807 | 240 | 4.2 |
| System6 p-Si | 20,810 | 87 | 239 | 4.2 |
| System7 p-Si | 89,587 | 384 | 233 | 4.3 |

### *3.8. $CO_2$ emission reduction*

As the PV systems do not require fossil fuels to generate electricity, their life-cycle $CO_2$ emissions are extremely low compared to electricity generated using conventional power plants. Therefore, the solar energy conversion using PV systems will result in a substantial reduction of $CO_2$ emissions. The equivalent $CO_2$ emissions avoided by using the PV systems have been calculated based on the $CO_2$ emission resulting from the conventional electricity generation in the UAE, which is about 938 g

$CO_{2eq}$/kWh [8]. The $CO_2$ emission from electricity generation in Western Europe is in the range 480–530 g $CO_{2eq}$/kWh [9,10]. In addition, 671 g $CO_{2eq}$/kWh was reported for Hong Kong [11], 12 g $CO_{2eq}$/kWh for Norway [10]. The difference in the amount of $CO_2$ emissions between these countries is due to various mixes in their electricity generation where renewable energy sources are used alongside conventional ones. Fig. 7 shows the annual equivalent saved $CO_2$ emissions from our seven PV systems where the total annual $CO_2$ emissions saved is found to be about 1,500 tons.

## 4. Conclusions

Seven roof mounted grid connected PV systems installed in Abu Dhabi, UAE, were analyzed using PVsysts Project Design and their performance parameters were evaluated on monthly and daily bases. The energy output, final yield, performance ratio, system and inverter efficiencies, capacity factor, and energy payback time for those PV systems have been evaluated.

The monthly energy output for PV System1 (a-Si) varied between 28,150 kWh in January and 50,170 kWh in May which is the best performance compared with the remaining six p-Si PV systems. However, the energy performance of the p-Si PV systems was better than System1 (a-Si) in winter and spring seasons. Moreover, the final yield and the performance ratio for System1 (a-Si) were higher than those obtained for the other simulated p-Si PV systems. The lower level of solar insolation during winter season resulted in lower final yield compared to summer season. The study showed that the seven simulated PV systems with a total installed capacity of 1,023.08 $kW_p$ can save up to 1,500 tons of $CO_2$ emissions annually.

The PV systems analyzed in this study showed a good energy performance which indicates that roof mounted PV systems in Abu Dubai are viable, reliable and can provide significant environmental benefits compared to conventional power plants.

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